



Isotopic and zooarchaeological approaches towards understanding aquatic resource use in human economies and animal management in the prehistoric Scottish North Atlantic Islands

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ABSTRACT

Despite being surrounded by aquatic resources, the Prehistoric populations of the North Atlantic Islands have a complex history of aquatic resource that until now has been little understood. Specifically the changing importance and uses of aquatic resources through time, and the role of aquatic resources in the management of animals in prehistory requires further attention. This paper presents results of faunal isotopic analysis in combination with existing human isotopic evidence and zooarchaeological datasets from Neolithic, Bronze Age and Iron Age sites in the Western Isles (also known as the Outer Hebrides) and Orkney to explore the importance of aquatic resources in the lives of these prehistory populations. In Orkney coastal grazing was an important aspect in the management of sheep throughout prehistory, whereas in the Western Isles this was only evident in the Bronze Age. Aquatic protein was also used in the management of pigs in the Western Isles during the Middle Iron Age. There is little evidence of humans consuming aquatic resources in the Neolithic, and only minor evidence of consumption in the Bronze Age. During the Iron Age aquatic resources become more important in the diet of humans. The Prehistoric Atlantic Islanders of Scotland had a complex and dynamic relationship with aquatic resources, especially in the role of animal management that changed throughout the course of prehistory.

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1. Introduction

The ecotonal coastal environments of the Scottish North Atlantic Islands provided a potentially wide and diverse resource base for the Prehistoric inhabitants. Previous research has demonstrated that despite many settlements lying close to the coast the Neolithic populations of Scotland ceased to consume aquatic protein in any great quantity following the arrival of agriculture to the region (Schulting and Richards, 2002) other than during times of famine (Montgomery et al., 2013). Post-Neolithic little is known about the importance of aquatic marine resources in insular prehistoric human and animal diets, with studies predominantly focussing on individual site analyses or individual periods (Bond, 2007; McCormick, 2006; Mulville, 1999; Mulville and Powell, 2012; Nicholson and Davis, 2007). The wealth of archaeological data existing in the Northern and Western Isles, located off of the North and West Coast of Scotland respectively (Fig. 1) presents a valuable opportunity to understand the role of aquatic resources in human economic practises and in the management of domestic species.

This paper builds on previous datasets and discussions of aquatic resource use in the Scottish North Atlantic Islands, where elements of these results have previously been presented (Cramp et al., 2014; Jones et al., 2012, 2013), but to date have not been used to fully explore animal husbandry practises in both island groups throughout prehistory, a crucial aspect in understanding the importance of aquatic resources in economic behaviour. The liminal Scottish Island environments would have posed a challenge for farmers, and there are speculations as to whether high cattle mortality is a result of milking strategies (Mulville et al., 2005a; Mulville et al., 2005b) or an extreme response to coping with marginal environments (McCormick, 1998). Shorefront resources may have proved a valuable management strategy for coping in these harsh environments, where finding suitable fodder for animals throughout the year would have been challenging. The objective of this paper is to characterise the economic importance of aquatic resources throughout prehistory in human animal diets, within the Scottish Atlantic Islands with an emphasis on the use of aquatic resources in animal husbandry practises within these liminal environments.

2. Investigating Scottish Atlantic Islands diets and economy

In the North Atlantic Islands a wealth of pioneering archaeological studies based on bulk collagen isotopic analysis, on human bone, to reconstruct prehistoric diet in the islands exist (Barrett and Richards,

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Fig. 1. A location map of the Scottish Islands, with a focus on the Western Isles and Orkney showing the relationship between the key sites mentioned in the text. Island groups are not to scale.

2004; Richards and Mellars, 1998; Schulting and Richards, 2002; Schulting and Richards, 2009; Schulting et al., 2010). These provide invaluable insights into the dominant foods consumed by human populations, but are less sensitive to low or occasional marine resource consumption (Hedges, 2004; Richards and Schulting, 2006). Integrating more traditional zooarchaeological methodologies with human isotopic evidence can provide different insights into marine resource use. Zooarchaeological research has a long history in the Scottish Isles, with analyses first published in the 1930s (Platt, 1934, 1937), and continues to be the primary method to assess diet and subsistence in the islands (Bond, 2007; McCormick, 2006; Mulville, 1999; Mulville and Powell, 2012; Nicholson and Davis, 2007). As zooarchaeological datasets can represent different timescales, from individual consumption events, to food debris accumulating over extended periods of time they can inform on infrequent or occasional uses of aquatic resource use where isotopic methods are not sensitive enough to do so (Hedges, 2004; Richards and Schulting, 2006). By applying stable isotope analysis of bulk bone collagen to zooarchaeological material animal management strategies can be explored (Madgwick et al., 2012a; Mulville et al., 2009; Stevens et al., 2010, 2013). The technique is crucial in identifying coastal grazing pastures and the input of marine resources into the diets of domestic animals (Müldner et al., 2014; Jones et al., 2012), informing on the importance of aquatic resources in animal management. Individually the isotopic and zooarchaeological datasets each provide information on different aspects of aquatic resources use on different scales, from long term consumption patterns to occasional or infrequent uses of marine resources, and the use of coastal pastures in the management of animals. Together this suite of datasets can provide a holistic understanding the role of aquatic resources in the lives of humans and animals in the Prehistoric Scottish Islands.

The Scottish Islands have a rich archaeological heritage, dating from the Neolithic onwards. This chronological span, in combination with the wealth of archaeological data makes them ideal locations to explore the role of aquatic resources in the islands across time. This paper is based on material from excavations across the archipelagos dating from the Neolithic (c. 4500 cal. BC to 2500 BC), Bronze Age (c. 2500 cal. BC to 600 cal. BC) and Iron Age (c. 600 cal. BC to 900 cal. AD) periods in the islands; with sites from all periods found across the island groups (Table 1) enabling chronological and spatial trends in diets and economies can be explored. The location of the key sites discussed in this study is shown in Fig. 1.

3. Materials and methods

Pre-existing human isotopic data was collated from published and unpublished sources, many of which were available from recently radiocarbon dated materials. The accuracy of isotopic results achieved through radiocarbon dating has been criticised as potentially being less precise than values acquired from collagen-specific analysis due to differences in the pre-treatment methods for radiocarbon dating techniques that may affect stable isotope values (Schulting and Richards, 2002, 163). Modern radiocarbon dating laboratories routinely analyse bulk collagen stable isotope values prior to graphitisation (see Brock et al., 2010), enabling greater reliability in results. Small scale comparisons of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ specific analysis with results achieved through radiocarbon dated demonstrated no difference between the two methodologies (Jay, 2005, 201). For specimens with isotopic measurements achieved through radiocarbon dating techniques, C:N ratios were consulted to ensure only specimens with high quality collagen were used. DeNiro (1985, 807) suggests that prehistoric specimens

Table 1

Table of Prehistoric Scottish Island sites and datasets, including broad chronologies of the sites, and publication references for the zooarchaeological data, isotopic values and used in this study.

Site name	Period	Period date range based on radiocarbon evidence	Zooarchaeological evidence	Faunal isotope specimens				Human isotopic evidence
				Cattle	Sheep	Pig	Dog	
Orkney	Neolithic c. 4500–1500 BC	3400–2900 BC (Dockrill et al., 2007)	Nicholson and Davis (2007)	2	6	3		Schulting et al. (2010)
Tofts Ness		3300–2600 BC (Schulting et al., 2010)	Clutton-Brock (1979)					
Quanterness		Not available	Smith (1994), Locker (1994)					
The Howe		2600–2700 BC (Ritchie, 1983)	Noddle (1983)					
Point of Cott								
Westray								
Knap of Howar		2800 and 3800 BC (Ritchie, 1983)	Noddle (1983)					
Pierowall Quarry		2600–1800 BC (Sharples, 1984)	McCormick (1984)					
Isbister		3500–2900 BC (Hedges, 1983)	Barker (1983)					
Links of Noltland		3400–1900 BC (Brend, 2010)	Armour-Chelu (1992)	10	10	4		
Skara Brae	Bronze Age c. 1500–700 BC	3700–1900 BC	(Cerrón-Carrasco et al., 2006)	7	7	2		Schulting and Richards (2009).
Pool		3300–2600 BC (Hunter et al., 2007)	Bond (2007)					
Ness of Brodgar		3000–2500 BC		7	2			
Holm of Papa		3600–2600 BC						
Westray		(Schulting and Richards, 2009)						
Bay of Moaness		1200–400 BC (Buckland et al., 1997)	Buckland et al. (1997)					
Tofts Ness		1400 BC (Dockrill et al., 2007)	Nicholson and Davis (2007)	5	5	1		
Skaill, Deerness		1500–800 BC (Buteux, 1997)	Noddle (1997)					
Point of Buckquoy		Not available	Bramwell (1976–77); Noddle 1976–77)					
Mine Howe	Iron Age c. 700 BC–900	Not available	Mainland and Ewens (2004); Mainland et al. (2003)	8	7	6		Shapland and Armit (2012). This study
Warebeth Broch	AD	AD 210 and AD 430 (Bell and Dickson, 1989)	Sellar (1989)					
Tofts Ness			Nicholson and Davis (2007)	4	5			
Skaill, Deerness		170 BC–80 AD (Buteux, 1997)	Noddle (1997)					
Pool		400 AD–800 AD (Hunter et al., 2007)	Bond (2007)	5	6	7		
Howe		380 BC–350 AD (Ballin Smith, 1994)	Smith (1994); Locker (1994)	4	2	2		
Lingro		Not available						
Broch of Gurness		Not available						
Knowe O'Skea		Not available		5	5	1	2	
The Cairns		Not available		5	3	2		
Buckquoy		Not available	Noddle (1997)					
Western Isles	Neolithic c. 4500–1500 BC	Not available	Serjeantson n.d.					Parker Pearson et al. (2005)
Udal North		3700 BC 2400 BC (Armit, 1989)		3	2			
Eilean Domhnuill		1600–1400 BC	Finlay (1984)	7	8			
Northton		Not available	Serjeantson n.d.					
Udal North		1290–840 BC (Barber, 2003)	Halstead (2003)					
Baleshare		2000–700 BC (Sharples, 2012b)	Mulville and Powell (2015)	2	4	1		
Sligenach		c. 1400–700 BC (Parker Pearson et al., 2005)	Mulville and Powell (2015); Ingrem (2015); Best and Powell (forthcoming))	24	21	3	5	
Cladh Hallan			Clarke (1960)					
A'Cheardach Mhor	Iron Age c. 700 BC–900	Not available	Finlay (1984)					Parker Pearson and Sharples (1999)
Sollas wheelhouse		Not available	Finlay (1984)					
Bruach Ban		Not available	Finlay (1984)					
Sligenach		760 BC–90 AD (Sharples, 2012b)	Mulville and Powell (2015)	5	5			
Sollas		20 AD–350 AD (Campbell et al., 1991)	Finlay (1984)					
Sheader (Search SY14)		Not available	Mulville (2000)					
Dun Vulcan		700 BC–500 AD (Parker Pearson and Sharples, 1999)	Mulville, 1999	7	7	8		
Mingulay MY384		Not available	Mulville (2000)					
Hornish Point		350 BC–390 AD (Barber, 2003)	Halstead (2003)					
Cnip		AD 60–AD 900 (Armit, 2006)	McCormick (2006)					
A'Cheardach Bheag		Not available	Fairhurst (1971)					Shapland and Armit Pers. Comm.
Bruthach a Tuath		Not available	Finlay (1984)					
Berigh		Not available	Thoms (2004)					
Sloc Sabhaidh				5	7	5	1	
Northton		340–540 AD	Finlay (1984)	4	4			Dawson Pers. Comm., Shapland and Armit Pers. Comm. Shapland and Armit Pers. Comm.
Udal North		Not available	Serjeantson n.d.					
Cladh Hallan		AD 20–250 (Parker Pearson et al., 2005)	Mulville and Powell (2015)	24	21	3	5	
Bornish		AD 210–900 (Sharples, 2012a)	Mulville and Powell (2012), Ingrem (2012)	21	15	11		
			Totals	133	131	61	10	

within the C:N range of 2.9–3.6 C:N are typical of in vivo collagen, with values outside of this indicative of contaminated collagen, and subsequently any human values outside of this range were excluded from consideration in this study (see supplementary dataset 2).

For the zooarchaeological comparison, the 'Number of Identified Specimen' (NISP) values were collated for mammals, fish and birds, as they represent the simplest form of zooarchaeological quantification, and are least subjected to analytical biases (Lyman, 2008). NISP counts can be influenced by differential bone survival, variable fragmentation patterns within and between and within sites (Chaplain, 1971; Grayson, 1973, 1979, 1984; Lyman, 2008; O'Connor, 2000, 2003), and can over-inflate the number of bones present (Lyman, 2008). Despite this, NISP is the most consistently recorded attribute within zooarchaeological assemblages, and thus the most comparable. To counteract sampling biases resulting in different quantities of bones present between sites percentage proportions of the total NISPs for each species was generated. Although often present in large quantities at site, shellfish and crustacea have not been included because they are frequently not quantified within zooarchaeological assemblages. Their inclusion would provide an indication of sampling strategy rather than meaningful patterns in resource use.

This paper presents the results of 335 domestic specimens (132 cattle-*Bos taurus*, 132 sheep-*Ovis aries* and 61 pig-*Sus scrofa* and 10 dog-*Canis familiaris*), a proportion of which have been presented previously as part of a broad baseline, and as average values (Jones et al., 2012, 2013; Mulville et al., 2009). By exploring these datasets together it is possible to determine changes in animal management and diets through time within both island groups. Only mature individuals, assessed using epiphyseal fusion and surface texture (Silver, 1969), were selected for analysis to avoid nursing signatures as these can cause inflated $\delta^{15}\text{N}$ values (Schurr, 1997, 1998). Different individuals were targeted by sampling the same skeletal elements from the same side of the body wherever possible to avoid repeat sampling of the same individual. Due to sampling restrictions, and gaps in the archaeological record there is an uneven distribution of results from across the archaeological sites and temporal periods.

Collagen extraction for faunal specimens followed the Longin (1971) method, with modifications as suggested by Collins and Galley (1998). Samples weighing between 0.7–0.9 g were drilled and cleaned using aluminium oxide air abrasion. Samples were demineralised in 0.5 M HCL at 6–8 °C for between 3 and 10 days. Specimens were washed three times using de-ionised water to remove any humic acid before being gelatinised in a weak acidic solution (pH 3 HCL) at 70 °C for 48 h. Samples were filtered using 5–8 μm Eze® mesh filters (Elkay Laboratory Products). Collagen extraction was undertaken at the Cardiff University Laboratory for Bioarchaeology. Isotopic analysis was funded by, and undertaken at the NERC Life Sciences Mass Spectrometry Facility in East Kilbride, UK. The extracted collagen was combusted using an ECS 4010 elemental analyser (Costech, Milan, Italy), coupled to a Delta V Plus isotope ratio mass spectrometer (Thermo Scientific, Bremen, Germany). The majority of specimens had %C values were greater than 35% and %N values over 10% as above, indicative of well-preserved collagen, and in the few instances where this was not evident, the specimens all fell well within an accepted C:N ratio (Supplementary dataset 1). All specimens included in this study had C:N ratios of between 3.2–3.5. The $\delta^{13}\text{C}$ values and $\delta^{15}\text{N}$ values are reported relative to the V-PDB standard and AIR standards. Based on replicate analysis of in-house laboratory standards, analytical error was 0.1‰ for $\delta^{13}\text{C}$ and 0.2‰ for $\delta^{15}\text{N}$ (σ_1). The results were tested for normality using the Shapiro–Wilk test, and deemed not to be normally distributed. Corresponding temporal periods were then tested statistically using a Mann–Whitney U test, using a post-hoc Holm–Bonferroni correction (Holm, 1979) by employing the ecological statistical programme 'PAST' (Hammer et al., 2001). A P-value of 0.05 or less was deemed to be indicative of a statistically significant result. Results are presented chronologically, first exploring human isotopic evidence and zooarchaeological datasets, before discussing evidence of animal diets.

4. Results

4.1. Neolithic

The human specimens from Neolithic Orkney exhibit elevated $\delta^{15}\text{N}$ values indicative of a relatively high protein diet, with values ranging between 10 and 12‰ (Fig. 2). The zooarchaeological record was dominated by terrestrial species (predominantly cattle and sheep) and contained very few fish, bird or marine mammal bone fragments (Fig. 3).

No human specimens were available from the Western Isles preventing the diet of humans from being assessed in this region at this time. As with Orkney, in the Western Isles aquatic species contribute only a small part of the zooarchaeological record, accounting for less than 5% of the total assemblage, with sheep, and cattle dominating the zooarchaeological record (Fig. 4).

The domestic faunal isotopic values from Neolithic Orkney (Fig. 5) includes three individuals with values elevated in $\delta^{13}\text{C}$ (above –20‰), indicative of the inclusion of marine plants in the diet. Overall the average values of sheep in Orkney ($\delta^{13}\text{C}$ –20.8‰, $\delta^{15}\text{N}$ 6.85‰) are higher in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ relative to cattle ($\delta^{13}\text{C}$ –21.7‰, $\delta^{15}\text{N}$ 5.92‰), and (p = for N, 0.001, p = 0.000 for $\delta^{13}\text{C}$) (Table 2).

Within the Western Isles none of cattle or sheep had isotopic values typically associated with the inclusion of marine products in their diet, and all had isotopic values typical of terrestrial food consumption (Fig. 6). There was little difference in the average values for cattle or sheep (Table 2) with no statistically significant difference was observed in either $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ (N; p = 0.067, C; p = 0.420).

4.2. Bronze Age

No human specimens were available from Orkney, preventing diet of humans from being assessed in this region at this time. The zooarchaeological record indicated that there was an increase in the representation of fish bones within the Bronze Age, and they account for around 20% of the total NISP (Fig. 3).

Within the Western Isles, only one human specimen, with a valid C:N ratio that could be included in this study (Parker Pearson et al., 2005). This individual had a $\delta^{13}\text{C}$ value of –19.9‰ and a $\delta^{15}\text{N}$ value of 10.8‰, 1.7‰ higher than average dog values analysed, and 3.3‰ higher than the average pig values (Fig. 7).

Within the Bronze Age faunal specimens from Orkney (Fig. 8) there was a statistically significant difference between the cattle and sheep $\delta^{13}\text{C}$ values (p = 0.02), with sheep (–20.3‰) being elevated in $\delta^{13}\text{C}$ relative to cattle (–21.5‰) (Table 2). For nitrogen, the average sheep $\delta^{15}\text{N}$ value was 1.1‰ higher than the cattle, this was not statistically significant (p = 0.27). The higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of sheep in both isotopes in relation to cattle.

Within the Western Isles the average $\delta^{13}\text{C}$ values of sheep are elevated by 0.85‰ relative to cattle (Table 2) and a statistically significant difference in $\delta^{13}\text{C}$ values was observed between cattle and sheep (p = 0.000). A 0.85‰ elevation in sheep nitrogen values was also observed, and this difference was statistically significant (p = 0.001). A single Bronze Age sheep from the Western Isles (Fig. 9) had a value of –19.0‰ $\delta^{13}\text{C}$.

4.3. Iron Age

There are three human specimens from Iron Age Orkney (Fig. 10), these are derived from the Broch of Gurness (this study), Lingro (Armit and Shapland pers. Comm.) and Newark Bay (Richards et al., 2006). The Late Iron Age specimen from Newark Bay (individual a) and was higher in both $\delta^{13}\text{C}$ (–17.9‰) and $\delta^{15}\text{N}$ (12.1‰).

Within the Western Isles four of the five directly dated human specimens (Fig. 11) from the Middle Iron Age site of Dun Vulan (Parker

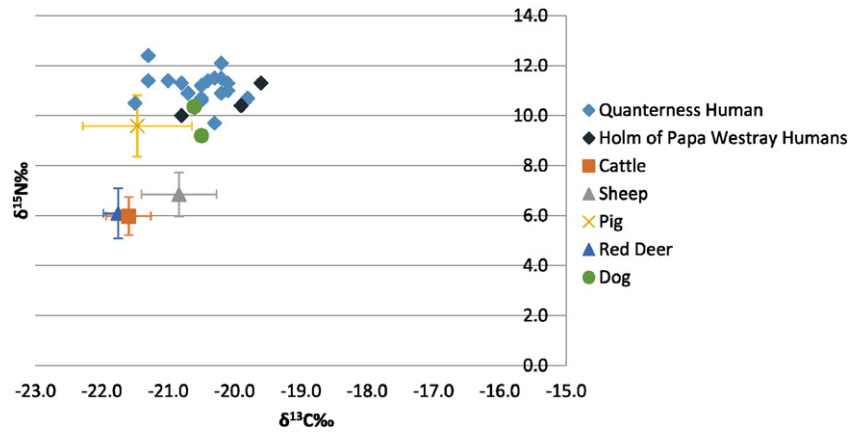


Fig. 2. Neolithic Orkney $\delta^{13}\text{C}\text{‰}$ and $\delta^{15}\text{N}\text{‰}$ values from individual human specimens (Schulting and Richards, 2009; Schulting et al., 2010), and mean faunal values, with error bars to 1σ .

Pearson and Sharples, 1999), had isotopic signatures consistent with a marine dietary component. One further individual from Cnip, a wheel-house settlement site on the Isle of Lewis (Shapland and Armit, 2012) and had a $\delta^{13}\text{C}$ value of -18.2‰ , and a $\delta^{15}\text{N}$ value of 12.3‰ , also indicative of marine food consumption. The other individuals from Baleshare, Bornais, and Northton had isotopic signatures that suggested a high protein diet. Finally there were two individuals with lower $\delta^{13}\text{C}$ values in relation to the other humans (see Supplementary dataset).

There is an increase in the number of fish bones present within the Western Isles zooarchaeological record, and they account for around 40% of the total NISP counts (Fig. 4), suggesting that they became more important in this period. The zooarchaeological evidence for Orkney (Fig. 3) showed a slight decrease in the proportion of fish bones present within the total zooarchaeological NISP for the island group from the Bronze Age to Iron Age.

In Iron Age Orkney isotopic analysis reveals that the sheep are elevated in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ relative to the cattle, with average sheep values 0.6‰ higher in $\delta^{13}\text{C}$, and 1‰ higher in $\delta^{15}\text{N}$ (Table 1) with the differences statistically significant ($\delta^{15}\text{N}$; $p = 0.000$, $\delta^{13}\text{C}$; $p = 0.002$). Of the individuals analysed one sheep and two pigs (Fig. 12) had $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values consistent with aquatic resource consumption.

The faunal remains in the Western Isles also demonstrate a greater utilisation of aquatic resources in the management of domestic animals. A cluster of pigs from Middle Iron Age phases of Dun Vulan have isotopic signatures consistent with the consumption of marine protein (Fig. 13). A further cluster of four individuals (3 from Bornais, 1 from Baleshare) (Fig. 13) were elevated in $\delta^{13}\text{C}$ to a lesser extent than the Dun Vulan specimens ($\delta^{13}\text{C}$ values $< 20\text{‰}$). When comparing average values, the

cattle and sheep had very similar $\delta^{13}\text{C}$ values (cattle; -21.8‰ , sheep -21.4‰), and no statistically significant differences were observed between them ($p = 0.609$) (Table 1).

5. Discussion

5.1. Coastal pasturing of herbivores

Within Holocene Britain an array of faunal bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotopic values have been published (Hamilton et al., 2009; Jay, 2005; Jay and Richards, 2006, 2007; Jay 2008; Lightfoot et al., 2009; Madgwick et al., 2012a, 2012b; Mulville et al., 2009; Schulting and Richards, 2002; Stevens et al., 2010, Stevens et al., 2013), and provide comparisons for animal management practises and diets within a range of ecosystems. Similarly, studies of animals grazing on coastal planes (Müldner et al., 2014), and in salt marshes (Britton et al., 2008), facilitate the interpretation of animals with isotopic values influenced by the consumption of plants within coastal ecosystems. There are a number of effects that the consumption of coastal products can have on isotopic values that can aid with the identification of individuals having marine influenced diets. Saline conditions can produce elevated $\delta^{13}\text{C}$ values of plants due to an influence on stomatal opening and therefore on the exchange with atmospheric carbon (Guy et al., 1986a,b; van Groenigen and van Kessel, 2002). Typically $\delta^{13}\text{C}$ values of herbivores infrequently reach $\delta^{13}\text{C}$ values beyond -20.5‰ (Müldner et al., 2014), and individual values beyond -20‰ can be interpreted as potentially having a saline influence in their diet. Coastal or salt marsh grazing of animals even on just a seasonal basis can produce an enrichment of

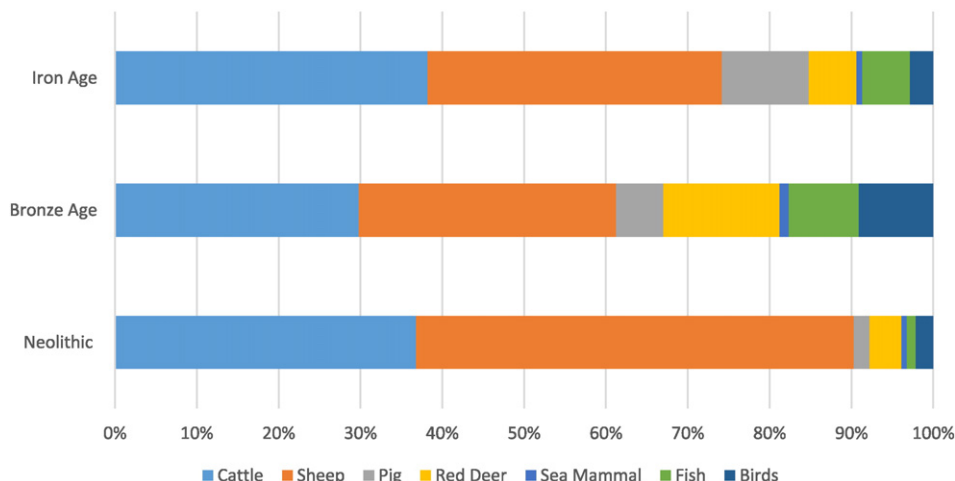


Fig. 3. NISP proportions of each resource type in Prehistoric Orkney (for zooarchaeological references see Table 1).

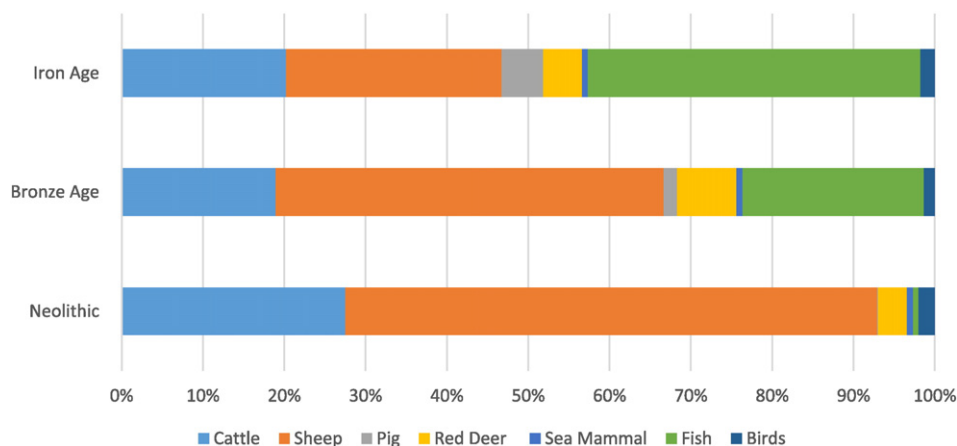


Fig. 4. NISP proportions of each resource type in Prehistoric Western Isles (for zooarchaeological references see Table 1).

$\delta^{15}\text{N}$ values within faunal specimens, as observed within sheep in the Severn Estuary (Britton et al., 2008) and in livestock grazing on the Flemish coastal plain (Müldner et al., 2014). Finally, differences between species can be used to potentially identify as a result of similar digestive systems the two main food animals cattle and sheep are generally not discernibly different in their isotopic values (Hofmann, 1989; Van Soest, 1984). Thus any variation between the average values of these species is indicative of differences in animal management and/or the resources consumed, and has been recognised as an indicator of dietary differences (Müldner et al., 2014). A combination of these indicators is used to identify the effects of coastal resource consumption on the Prehistoric animals in the North Atlantic Islands.

The effects of salinity or grazing of animals on coastal plants can be observed within several of the prehistoric periods in the Scottish Islands. In Orkney during the Neolithic, Bronze Age and Iron Age the sheep were elevated in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ relative to the cattle, to a statistically significant degree. This suggests that sheep were either being grazed on the shorefront, in saltmarsh areas, or were foddered on crops fertilised using seaweeds, enriching the spoils, and producing higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in the plants growing there, and subsequently the animals consuming them. As some individuals had higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values than others, this indicates some animals were consuming greater quantities of coastal plants. The relatively low $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of cattle suggests that they were being kept further away from the coastal saline environments, and did not have an aquatic component to their diet. A similar pattern was observed on the Flemish coastal plain where sheep consistently exhibited higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values whilst cattle had consistently lower values indicative of the

choice of different foddering locations/strategies (Müldner et al., 2014). Isotopically, distinguishing between coastal and salt marsh grazing is not possible, and wider evidence needs to be considered. Today ethnographic observations on North Ronaldsay, Orkney demonstrate that sheep rely heavily on seaweed as a dietary component, feeding on brown kelp washed ashore in storms (Balasse et al., 2005, 2006, 2009; Mainland, 2000), providing an analogue for the archaeological animals. Interpretations of isotopic data based on Incremental analysis of sheep teeth has provided additional evidence for seaweed consumption within at least some individuals, at the Neolithic sites of Point of Cott and Holm of Papa Westera, Orkney (Balasse et al., 2009; Balasse et al., 2006) and at Iron Age Mine Howe (Balasse et al., 2009; Balasse et al., 2006). Microwear analysis of sheep teeth in Orkney provides evidence for the consumption of seaweed within modern populations (Mainland, 2000), and in the future could facilitate the identification of salt marsh versus coastal/seaweed grazing. For the isotopic values of the sheep to be affected, the practise of coastal pasturing must have been a regular, long term, activity. During prehistory the shorefront was used as a valuable sheep grazing location at certain times of year when other food sources were not available. For example during the winter months seaweed, which is a plentiful resource in the islands, would have provided a nutritious and plentiful resource.

In the Western Isles herbivores are managed differently to those in Orkney, with the shorefront not consistently used as a sheep foddering location, despite the presence of salt marshes, and coastal pastures throughout the machair environments along the West Coast of the island group (Dickinson and Randall, 1979). In the Neolithic and Iron Age periods cattle and sheep have similar average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values,

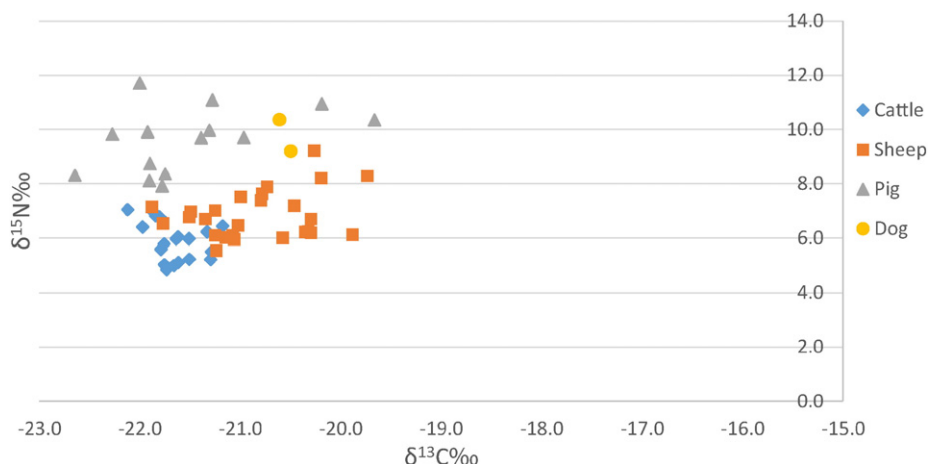


Fig. 5. Neolithic Orkney individual specimen values for the major domesticates; cattle, sheep and pig.

Table 2

Faunal isotopic results for each prehistoric period in the North Atlantic Islands.

	N	Mean $\delta^{15}\text{N}\text{‰}$	Min $\delta^{15}\text{N}\text{‰}$	Max $\delta^{15}\text{N}\text{‰}$	Stand. Dev $\delta^{15}\text{N}\text{‰}$	Mean $\delta^{13}\text{C}\text{‰}$	Min $\delta^{13}\text{C}\text{‰}$	Max $\delta^{13}\text{C}\text{‰}$	Stand. Dev $\delta^{13}\text{C}\text{‰}$
<i>Neolithic Orkney</i>									
Cattle	20	5.9	4.8	7	0.7	−21.7	−22.1	−21.2	0.2
Sheep	26	6.9	5.5	9.2	0.9	−20.8	−21.9	−19.7	0.6
Pig	14	9.6	7.9	11.7	1.2	−21.5	−22.6	−19.7	0.8
<i>Neolithic Western Isles</i>									
Cattle	9	4.3	6.3	5.2	0.6	−21.9	−20.9	−21.4	0.3
Sheep	11	4.6	7.4	5.7	0.7	−22.4	−21.3	−21.6	0.3
<i>Bronze Age Orkney</i>									
Cattle	5	6.6	6.0	7.0	0.4	−21.7	−21.8	−21.5	0.1
Sheep	4	7.7	5.9	8.9	1.3	−20.6	−21.0	−20.3	0.3
Pig	2	6.9	5.4	8.3	2.1	−21.5	−21.8	−21.1	0.5
<i>Bronze Age Western Isles</i>									
Cattle	27	5.2	4	6.3	0.7	−21.4	−22.3	−20.1	0.6
Sheep	25	6.0	3.2	7.9	1.1	−20.5	−21.7	−19.0	0.6
Pig	4	7.5	4.9	10.2	2.2	−21.0	−22.3	−19.8	1.1
<i>Iron Age Orkney</i>									
Cattle	30	5.7	4.9	7.6	0.6	−21.9	−22.6	−21.4	0.3
Sheep	27	6.7	4.3	9.0	1.0	−21.3	−22.4	−19.1	0.8
Pig	19	8.9	4.7	16.5	2.5	−20.3	−21.9	−13.6	1.9
<i>Iron Age Western Isles</i>									
Cattle	49	4.7	3.5	6.4	0.6	−21.2	−21.8	−20.4	0.4
Sheep	31	5.2	3.7	10.0	1.3	−21.1	−22.0	−19.8	0.5
Pig	33	7.6	4.6	12.1	1.7	−20.6	−22.3	−16.8	1.3

with no statistically significant differences between datasets observed. This suggests sheep and cattle were foddered away from the shore front and were not exposed to a diet including saline plants. In the Bronze Age sheep have higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, which were statistically significantly different to the cattle values but similar values to those observed in the Bronze Age Severn estuary (Britton et al., 2008) indicative of the consumption of plants growing in saline conditions. In the Western Isles there is less of a reliance on coastal environments in the management of sheep whilst in Orkney coastal grazing is used throughout prehistory, showing different approaches to coping in these environments.

6. Discussion: temporal trends in diet

6.1. Neolithic- terrestrial protein consumption

Within the human specimens, similar principles to those used for the animal specimens can be used to identify marine protein consumption. Consumers of animal protein are typically expected to be roughly

one trophic level higher than herbivores analyse 3–5‰ (Hedges and Reynard, 2007), thus consumption of large quantities of animal protein can create higher $\delta^{15}\text{N}$ values (Schoeninger and De Niro, 1984; Hedges and Reynard, 2007). Typically an increase in $\delta^{13}\text{C}$ (approx. 1–1.5‰) is also observed with trophic stage, in accordance with the rise in $\delta^{15}\text{N}$ (Dürrwächter et al., 2006). If aquatic foods are being eaten a shift in both $\delta^{15}\text{N}$ values, and the $\delta^{13}\text{C}$ values is expected to be seen, depending on the quantity and regularity of consumption. Baseline values of herbivores are crucial in differentiating between these signatures. As with fauna analysed, humans with $\delta^{13}\text{C}$ values past −20 may have a minor marine influence in their diet, either by low level direct consumption, or by eating consumers of marine protein. The humans in Orkney had high $\delta^{15}\text{N}$ values, and could be the product of several possible factors; consumption of ‘invisible’ marine resources, eating foods from fertilised or manured land, or consumption of high levels of terrestrial protein in the form of meat or milk.

The possibility of ‘invisible’ marine resource consumption in the Neolithic has been highlighted by Milner et al. (2004). Bone collagen stable isotope analysis is biased towards reflecting the protein content

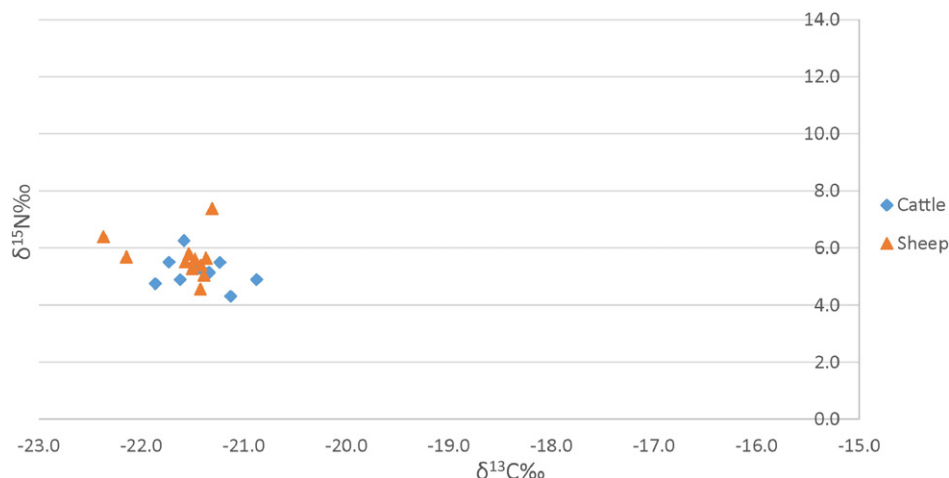


Fig. 6. Neolithic Western Isles individual specimen values for the major domesticates; cattle, sheep and pig.

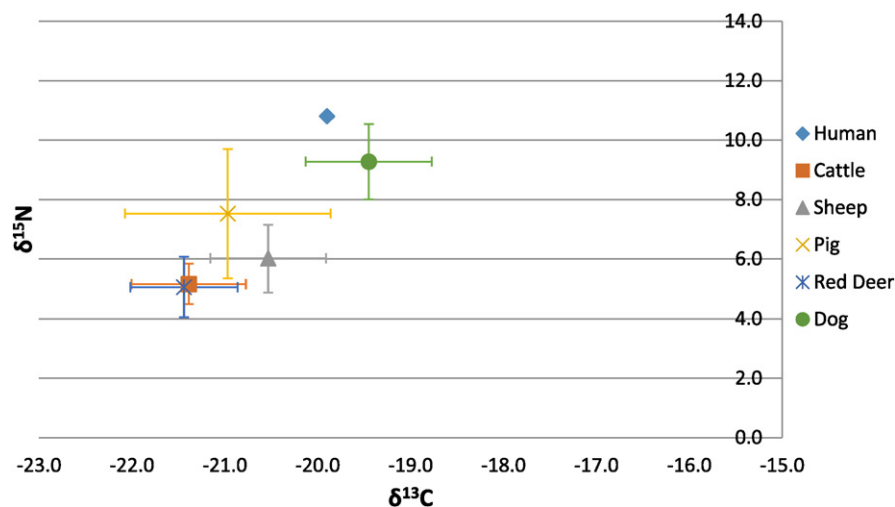


Fig. 7. Bronze Age Western Isles individual human $\delta^{13}\text{C}$ ‰ and $\delta^{15}\text{N}$ ‰ value (from Parker Pearson et al., 2005), and mean faunal values, with error bars to 1 σ .

of diet, and lipids or carbohydrates may not be fully reflected in the $\delta^{13}\text{C}$ isotopic signature (Milner et al., 2004). The consumption of marine lipids, such as in marine mammals could be an ‘isotopically visible’ food source, although the exceedingly low NISP of marine mammal fragments, and the absence of marine lipids in any Neolithic Scottish Island vessels analysed (Cramp et al., 2014) suggests that this explanation is unlikely. The zooarchaeological record shows very low frequencies of fish bones or marine mammal remains, accounting for less than 2% of the total NISP, indicating that consumption of these products is not enough to sufficiently affect the isotopic values. Recent incremental isotope analysis of human tooth specimens from Neolithic West Voe, Shetland, demonstrated that the population at the site was only consuming marine foods during times of extreme famine, which was not evident in the bulk collagen results (Montgomery et al., 2013). If the Neolithic Orkney individuals were consuming lower quantities of marine foods, as seen in the zooarchaeological record, the bulk collagen nitrogen values would likely not be affected. Low level marine or invisible marine consumption are therefore not a viable explanation for the high $\delta^{15}\text{N}$ values seen in the Neolithic Orkney population.

Manuring or soil fertilisation can elevate $\delta^{15}\text{N}$ values within plants, and their consumers (Fraser et al., 2011; Bogaard et al., 2007; Bogaard et al., 2013), and this practice has been identified isotopically within Neolithic populations in Europe (Bogaard et al., 2013). The humans from Orkney could have been consuming products grown on fertilised land, which may even have been fertilised by seaweed. If fertilisation

of crops was being practised, elevated $\delta^{15}\text{N}$ values would be expected to be seen in animals too (Bogaard et al., 2007). Within this dataset the sheep and cattle values are all at about 6–7‰ in $\delta^{15}\text{N}$, and plot with the wild red deer which is lower than would typically be expected for consumers of plants grown on fertilised or enhanced soils, and another explanation is sought.

High levels of meat and milk protein is the final possible explanation for the high $\delta^{15}\text{N}$ values seen in the Neolithic Orkney specimens. The $\delta^{15}\text{N}$ values of individuals increase with trophic level, and foods that are higher in protein have a greater impact on the bone collagen isotopic signatures (Ambrose and Norr, 1993; Hedges and Reynard, 2007; Howland et al., 2003; Tieszen and Fagre, 1993). Consumption of large quantities of animal protein would have a greater impact on the bone collagen $\delta^{15}\text{N}$ values observed within these individuals. Sheep, and to a lesser extent cattle, dominate the zooarchaeological record at this time, both of which would have been definitely sources of both meat and milk for these island populations. The presence of dairy fat residues within all Neolithic ceramic vessels analysed from the islands suggests that ungulate milk and milk products were a crucial form of protein at this time (Cramp et al., 2014); a phenomenon also observed in mainland Britain (Copley et al., 2003). This is consistent with the higher $\delta^{15}\text{N}$ values seen within the Neolithic humans from Orkney, making this the most plausible explanation for these isotopic values observed. The slightly higher $\delta^{13}\text{C}$ values are likely influenced by consuming sheep that had small aquatic dietary input as discussed above. The evidence indicates that terrestrial protein was an important part of diet for

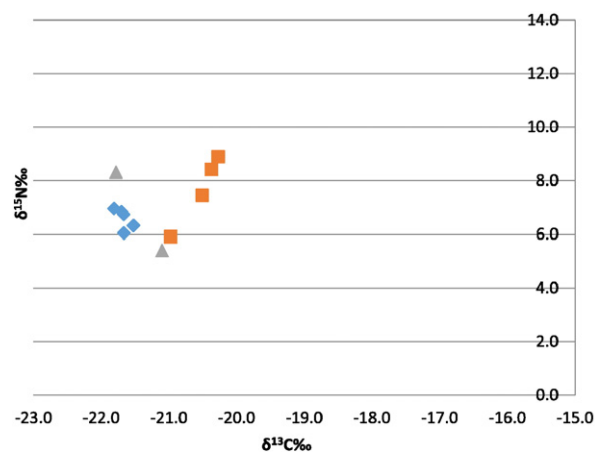


Fig. 8. Bronze Age Orkney individual specimen values for the major domesticates; cattle, sheep and pig.

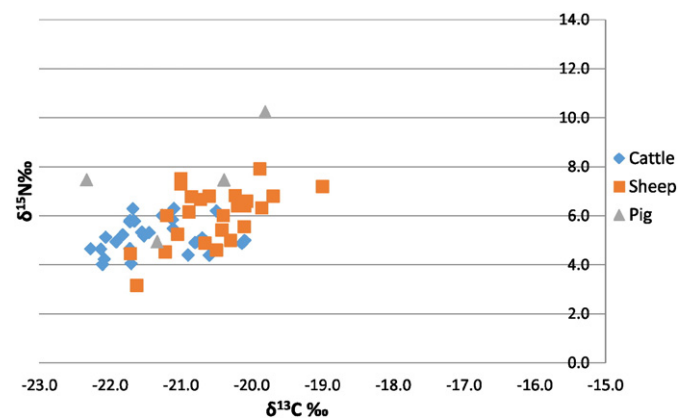


Fig. 9. Bronze Age Western Isles individual specimen values for the major domesticates; cattle, sheep and pig.

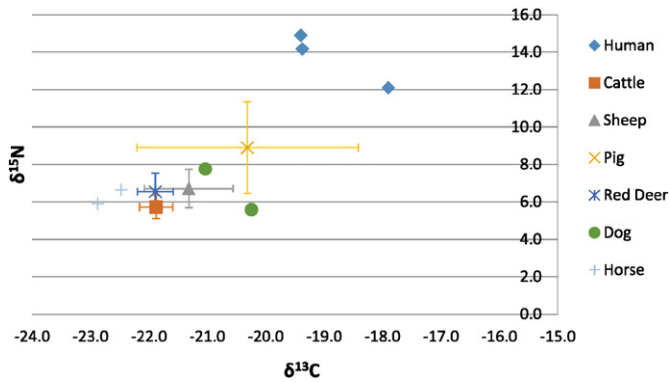


Fig. 10. Iron Age Orkney $\delta^{13}\text{C}\%$ and $\delta^{15}\text{N}\%$ values from individual human specimens (Armit and Shapland Pers. Comm; Richards et al., 2006; this study), and mean faunal values, with error bars to 1 σ .

the Neolithic populations of Orkney. Aquatic resources were not commonly consumed directly by humans in the Scottish Atlantic Islands, instead terrestrial protein sources in the form of meat and milk were a crucial to the diet of these early farming populations, which is consistent with and confirms that direct consumption of aquatic resources was not routinely practised in the Neolithic as previously suggested (Schulting and Richards, 2002).

6.2. Bronze Age — occasional aquatic resource consumption

The one Bronze Age human from Cladh Hallan is roughly 4‰ higher in $\delta^{15}\text{N}$ than the herbivore specimens, and the $\delta^{13}\text{C}$ value is around 1‰ higher, typical of values expected for a consumer-prey relationship (Hedges and Reynard, 2007). This, as with the Neolithic is likely indicative of diet intensive of consumption of terrestrial animal protein likely as meat or milk. As with the Neolithic, pottery residues indicate that ruminant fat and dairy fats were important in the islands during the Bronze Age (Cramp et al., 2014), which is consistent with the zooarchaeological evidence which continues to be dominated by sheep and cattle at this time.

The increased quantity of fish bones in the Bronze Age assemblages of the Western Isles indicates that fish were more important at this time despite not being represented in the human bone collagen. Fish may have been a seasonal resource; the predominant fish species at Cladh Hallan was juvenile saithe (Ingrem, 2015), which are typically plentiful in the late summer/early autumn months (Ingrem, 2012). If saithe were

being fished and consumed directly at this time of year this suggests the seasonal utilisation of resources. With significant evidence for milk production (Mulville and Powell, 2015) probably in the summer months, assuming a spring birthing season (Mulville et al., 2005b), the exploitation of saithe during the late summer/early autumn would fill the dietary protein gap at the end of the milking season. Another possibility is that fish were caught during summer and early autumn to take advantage of their seasonal availability, but were then preserved and stored (by drying) to utilise in the future, as an emergency resource. In Orkney greater proportions of fish bones are also evidence, indicative of their increased importance in this island groups also at this time.

6.3. Iron Age — increasing marine resource use

During the Iron Age there is zooarchaeological evidence for only minor aquatic resource consumption in Orkney. The overall low proportions of fish bone contrast with some of the human isotopic evidence, as one individual had a signature consistent with the consumption of some marine products, and two human values were past -20% potentially indicative of a low level marine input in the diet. This individual dates to Late Iron Age at Newark Bay (1340 ± 60 , TO-7191 Richards et al., 2006), indicating a possible increase in marine resource use at the end of the Iron Age, approaching the beginning of the Norse period.

In the Western Isles aquatic resources appear to gain in importance from the Middle Iron Age onwards (c. 200 BC–400 AD), with 4 pigs consuming marine protein in sufficient quantities to affect both their isotopic value, and potentially that of the humans who fed upon them. The isotopic evidence is supported by an increase in the proportions of aquatic resources identified within the zooarchaeological deposits. The pig isotopic values within the Iron Age Western Isles were typical of marine protein consumption. This could be the result of pigs eating shellfish, either through self-selection or deliberate foddering, as porcine consumption of shellfish and fish has been observed in the islands of Brittany (Cocaign, 1999), and suggested for wild pigs in the Baltic Mesolithic (Zvelebil, 1995). Whilst no shellfish data were published for Dun Vulan tens of thousands of limpet fragments were recovered from the site (Sharples, 2005), and the limpet flesh could have been consumed by pigs. Hedges (2004, 35) suggests that shellfish have a lesser impact on $\delta^{13}\text{C}$ values per volume than other marine products, and to have an impact on the isotopic ratio the pigs from Dun Vulan would have had to have consumed substantial quantities of shellfish. Mollusca are also hypothesised as having $\delta^{13}\text{C}$ values ranging between -23 to -14 due to absorbing elements of terrestrial carbon, and subsequently have a lesser impact on the $\delta^{13}\text{C}$ within bone collagen of individuals (Milner

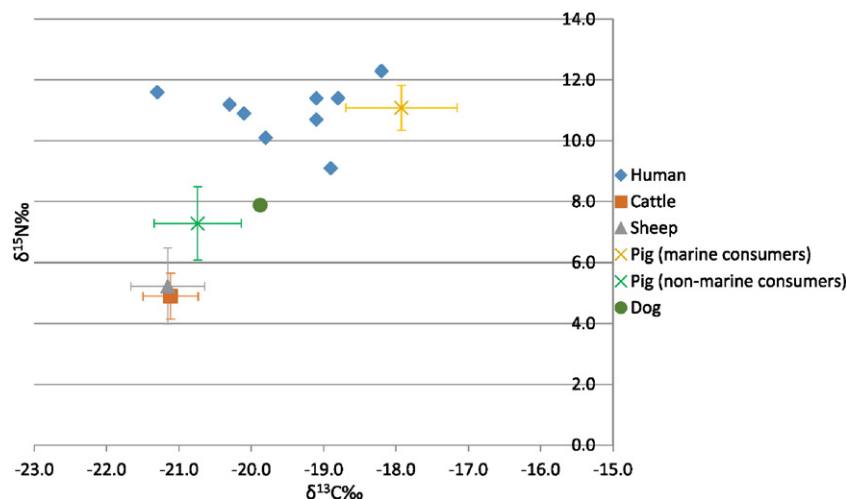


Fig. 11. Iron Age Western Isles $\delta^{13}\text{C}\%$ and $\delta^{15}\text{N}\%$ values from individual human specimens (Parker Pearson and Sharples, 1999; Armit and Shapland Pers. Comm. And Dawson pers. Comm.), and mean faunal values, with error bars to 1 σ .

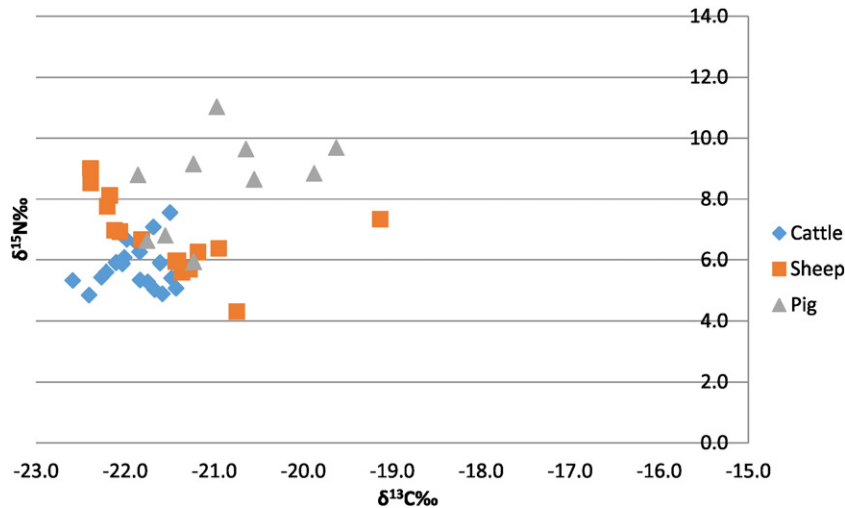


Fig. 12. Iron Age Orkney individual specimen values for the major domesticates; cattle, sheep and pig.

et al., 2004, 16). Thus the higher $\delta^{13}\text{C}$ values in combination with the elevated $\delta^{15}\text{N}$ values of the individuals from Dun Vulan in combination with are indicative of a consumption of food sources higher up the food chain such as fish. One possibility is that pigs were being fed waste products from fish processing, such as fish heads, which are frequently removed during processing of fish (Barrett, 1997). If this was the case we would expect to see differences in the body part representation of the fish skeletons, where fewer cranial elements are preserved within the assemblage. At Dun Vulan fish body analysis revealed that the assemblage comprised 49% of body elements and 51% of head elements (Cerón-Carrasco and Parker Pearson, 1999, 281), which suggests that the pigs were not just being fed waste cranial elements, which would have created an assemblage with a greater proportion of body elements. If the Dun Vulans were consuming fish, then they must have been consuming entire fish, based on the body part representation evidence.

The Middle Iron Age Human isotope values from the Western Isles plot in the same location as the pigs with aquatic isotopic signatures; if humans were consuming substantial quantities of pork from marine fed animals their nitrogen values would be elevated by 2–3‰ more than the pigs. As this is not observed, humans were either consuming pigs infrequently or were consuming marine protein in lower quantities than the pigs. Both scenarios are consistent with the zooarchaeological evidence with only a small number of pigs with a marine signature

and an increasing number of fish present. In addition to increased aquatic resource use, increased numbers of pigs are present within the zooarchaeological assemblage at the site of Dun Vulan (Mulville, 1999), potentially indicative of hierarchical behaviour or a higher status of this Broch site (Parker Pearson et al., 1996). Traditional accounts of subsistence in Iron Age Britain, based on zooarchaeological evidence from mainland Britain suggest that marine foods were not utilised to any great extent during the Iron Age (Champion and Collis, 1996; Cunliffe, 1995; Dobney and Ervynck, 2007; Green, 1992). Similarly isotopic studies from a range of coastal and inland sites within mainland Britain indicate that there was little or no marine dietary input at this time (Jay and Richards, 2006, 2007; Jay, 2005, 2008). The absence of fish bones on mainland British Iron Age sites in the North Sea region has been attributed to ideological beliefs or taboos held by these populations (Dobney and Ervynck, 2007). The combined results from human and faunal isotopic and zooarchaeological evidence from the Western Isles, and to a lesser extent Orkney, indicates that at least in the Scottish Isles, marine resources were being used by populations and there was no taboo against consumption in these locales, although not be all members of the populations.

The consumption of aquatic resources by humans and pigs at Dun Vulan may be linked to concepts of feasting and maintaining or building social cohesion. The production of surpluses has long been suggested as

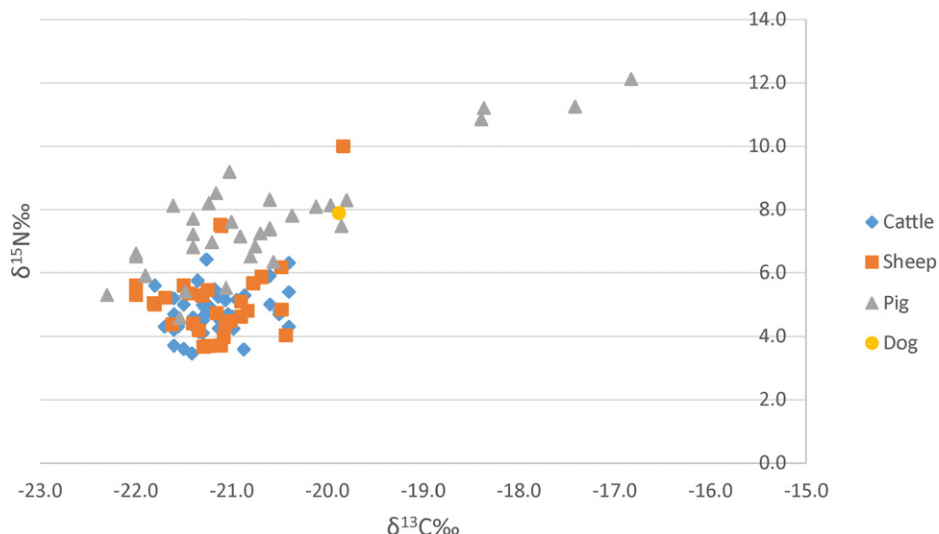


Fig. 13. Iron Age Western Isles individual specimen values for the major domesticates; cattle, sheep and pig.

a mechanism for controlling trade, securing a hierarchical position and maintaining status (Sharples, 1991; Haselgrove, 1999; Cunliffe, 1991). van der Veen (2007, 121) suggests that grain surpluses were produced in the Middle Iron Age to use for feasting as a method of demonstrating hierarchy and encouraging social cohesion, and as incentive building or maintenance projects. It is possible that feasting on marine products was utilised as a technique to construct the impressive broch structures such as Dun Vulan. Pigs have been suggested as a high-status product utilised for feasting in Scottish Iron Age societies (Parker Pearson and Sharples, 1999, 46; Parker Pearson et al., 1996), and it is possible that marine foods were being deliberately fed to pigs intended for feasting purposes. Only some of the pigs analysed had a marine isotopic signature, supporting the argument that these animals may have been prepared and for special occasions during the Middle Iron Age occupation of the site.

The Iron Age populations of the North Atlantic Islands were culturally distinct from their counterparts in neighbouring mainland Britain. They constructed stone-built roundhouses, whereas in Southern and Eastern Scotland, like mainland Europe, they built timber buildings and hillforts (Armit, 1990, 436). The North Atlantic insular populations chose to selectively adopt only some aspects of the material culture observed in mainland Britain during the 3–4th Century BC (Sharples, 2012a, 19). This cultural and temporal difference between the Western Isles, and mainland Britain during the Iron Age and could explain the differences in dietary behaviour observed between these regions.

7. Conclusions

The results show that the prehistoric populations of the Scottish North Atlantic Islands had a complex and dynamic relationship with the sea, with both island groups having different economic strategies within these marginal locations. Coastal pastures and marine plants were an important part of animal management throughout prehistory in Orkney, and within the Bronze Age in the Western Isles, possibly as a seasonal resource in the less fruitful winter months. Across the islands aquatic resources were not commonly eaten by humans during the Neolithic, supporting previous research into human diet (Schulting and Richards, 2002). In the Bronze Age there is a slight increase in the consumption of marine foods, as shown by the greater representation of fish bones within zooarchaeological assemblages. Within the Iron Age, particularly in the Western Isles there is increasing evidence of aquatic resource consumption, with a further increase in the representation of fish bones accompanied by clear isotopic evidence of humans consuming aquatic protein, indicating that marine protein was important at this time. Shorefront and coastal grazing locations were an important part of animal management. This was manifested in Orkney by sheep being consistently elevated in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ relative to cattle during the Neolithic, Bronze Age and Iron Age, with some individual specimens exhibiting clear evidence of marine plant consumption. In the Western Isles the situation differed with elevated sheep values only observed in the Bronze Age. During the Iron Age Middle Iron Age pig specimens from Dun Vulan pigs were also consuming aquatic protein, suggesting it was an important aspect of animal management at this time. This is contra to practises observed in Iron Age mainland Britain, where humans and animals had exclusively terrestrial diets, highlighting a crucial difference in the Iron Age populations of the Scottish Islands.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.jasrep.2015.08.019>.

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